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Title: MEASURING RANGE AND/OR RADIAL VELOCITY OF A MOVING TARGET ;

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Inventor(s): STOVE ANDREW GERALD ;

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IPC Classification: G01S13/34; G01S13/52; G01S13/62 ;

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ABSTRACT:

A continuous-wave FM radar system comprises a voltage-controlled RF oscillator (1) the output frequency of which is swept repeatedly in both senses by means of a voltage waveform generator (19), whose waveform cycle comprises two upward sweeps followed by two downward sweeps. The oscillator output signal is fed to an aerial (3) and a portion of the transmitted signal is mixed with the return signal in a mixer (7). The ranges and/or velocities of reflecting moving targets are determined by means of a computer (100) which is fed with the output of a spectrum analyser (15) for the resulting beat-frequency signals, range-velocity ambiguities due to Doppler shifts being resolved by determining each range and/or velocity from a pair of spectral frequencies which arise from sweeps of the oscillator frequency in one sense and in the other sense respectively. In order to make the task of the computer easier in deciding which frequencies constitute related pairs a signal storage and differencing circuit (11) subtracts the mixer output signals which arise from successive sweeps of the oscillator frequency in the same sense one from the other and feeds only the result to the spectrum analyser, thereby ensuring that the spectral frequencies outputted by the spectrum analyser correspond only to moving targets.

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(71) Applicant
Philips Electronic and Associated Industries Limited (United Kingdom),
Arundel Great Court, 8 Arundel Street, London WC2R 3DT

(72) Inventor
Andrew Gerald Stove

(74) Agent and/or Address for Service
R. J. Boxall, Mullard House, Torrington Place, London WC1E 7HD

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(58) Field of search
H4D
Selected US specifications from IPC sub-class G01S

(54) Measuring range and/or radial velocity of a moving target

(57) A continuous-wave FM radar system comprises a voltage-controlled RF oscillator (1) the output frequency of which is swept repeatedly in both senses by means of a voltage waveform generator (19), whose waveform cycle comprises two upward sweeps followed by two downward sweeps. The oscillator output signal is fed to an aerial (3) and a portion of the transmitted signal is mixed with the return signal in a mixer (7). The ranges and/or velocities of reflecting moving targets are determined by means of a computer (100) which is fed with the output of a spectrum analyser (15) for the resulting beat-frequency signals, range-velocity ambiguities due to Doppler shifts being resolved by determining each range and/or velocity from a pair of spectral frequencies which arise from sweeps of the oscillator frequency in one sense and in the other sense respectively. In order to make the task of the computer easier in deciding which frequencies constitute related pairs a signal storage and differencing circuit (11) subtracts the mixer output signals which arise from successive sweeps of the oscillator frequency in the same sense one from the other and feeds only the result to the spectrum analyser, thereby ensuring that the spectral frequencies outputted by the spectrum analyser correspond only to moving targets.

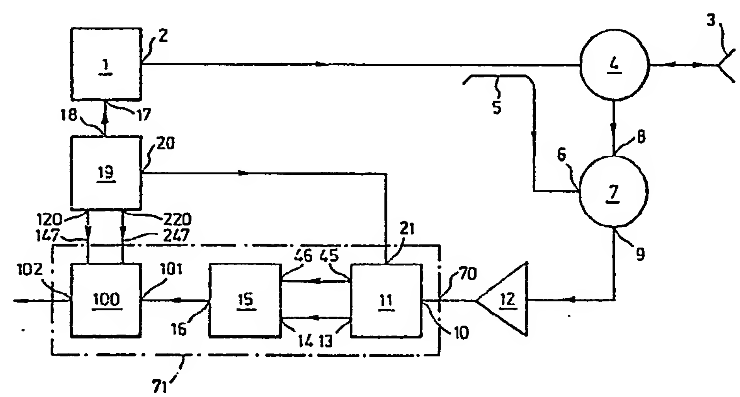

Fig.1.

The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

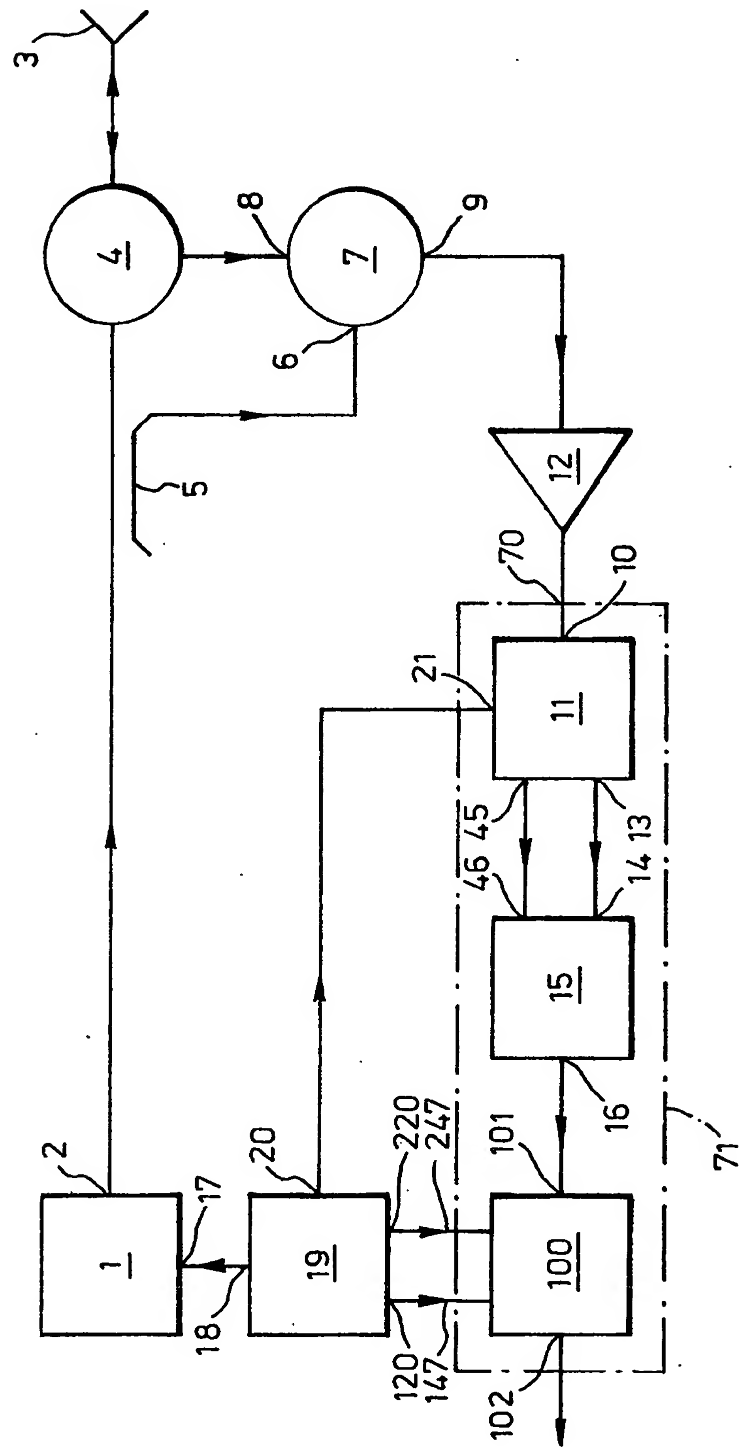
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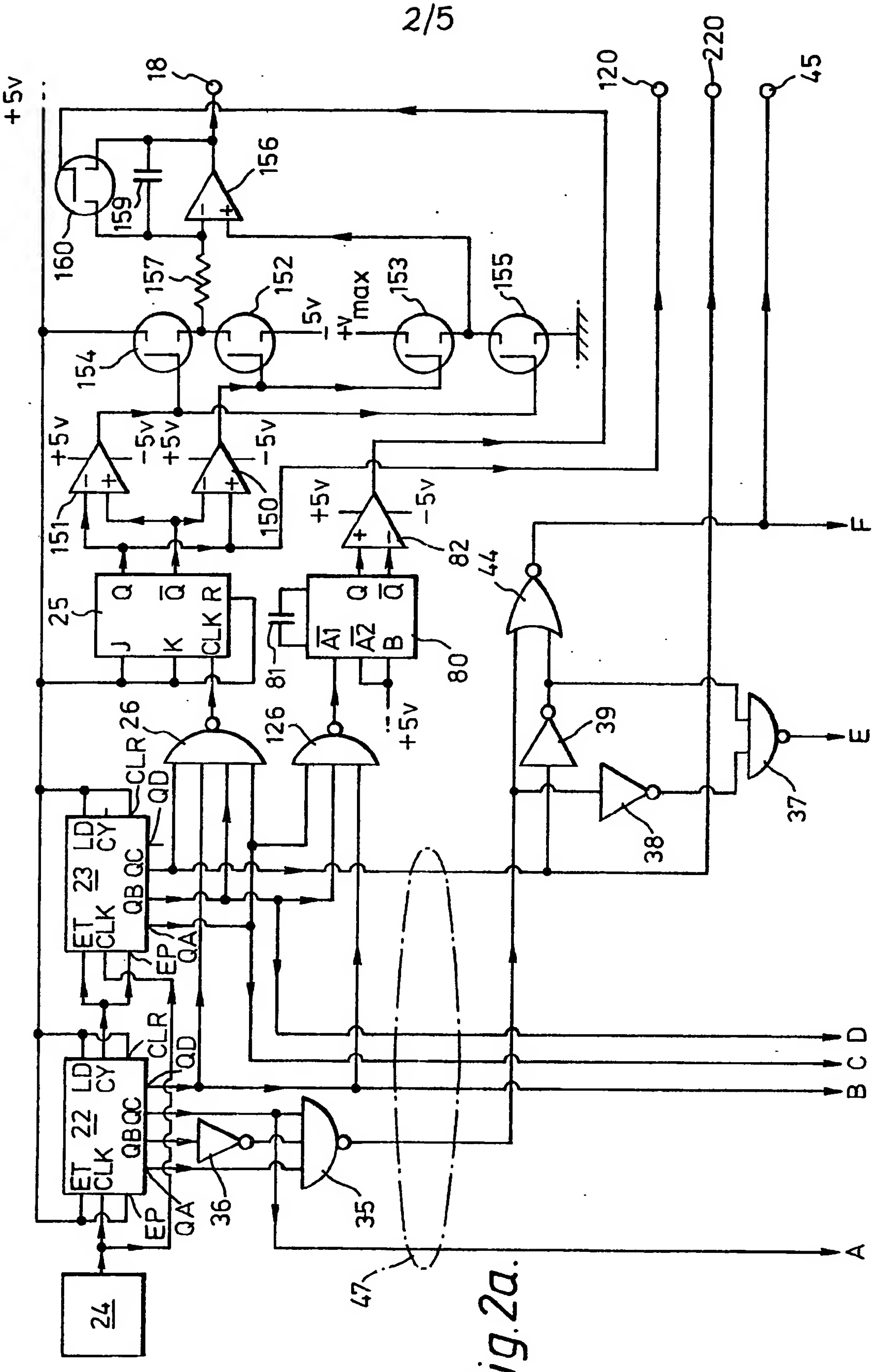
Fig.1.



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ET
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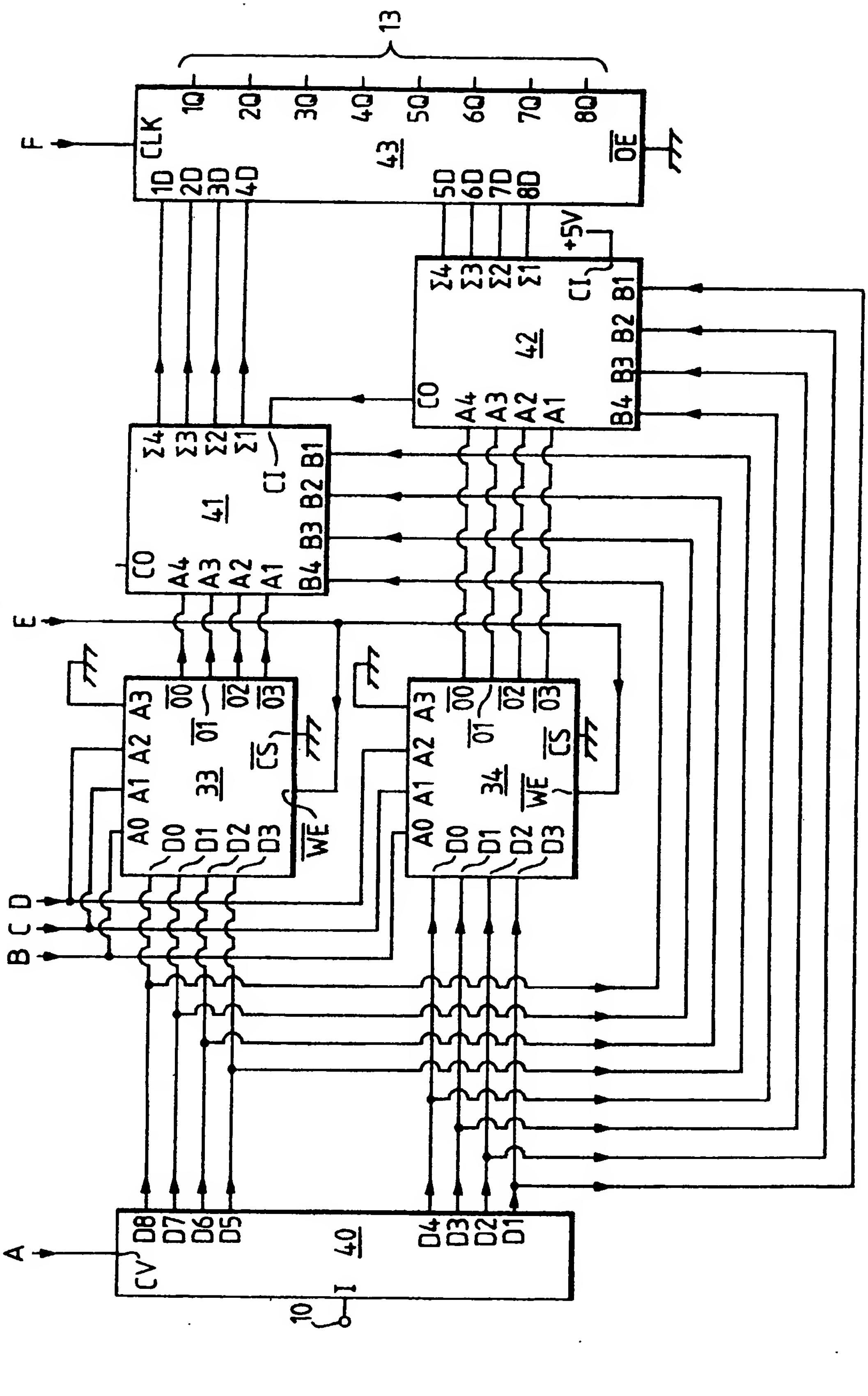
Fig.2a.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Σ4
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Fig.2b.

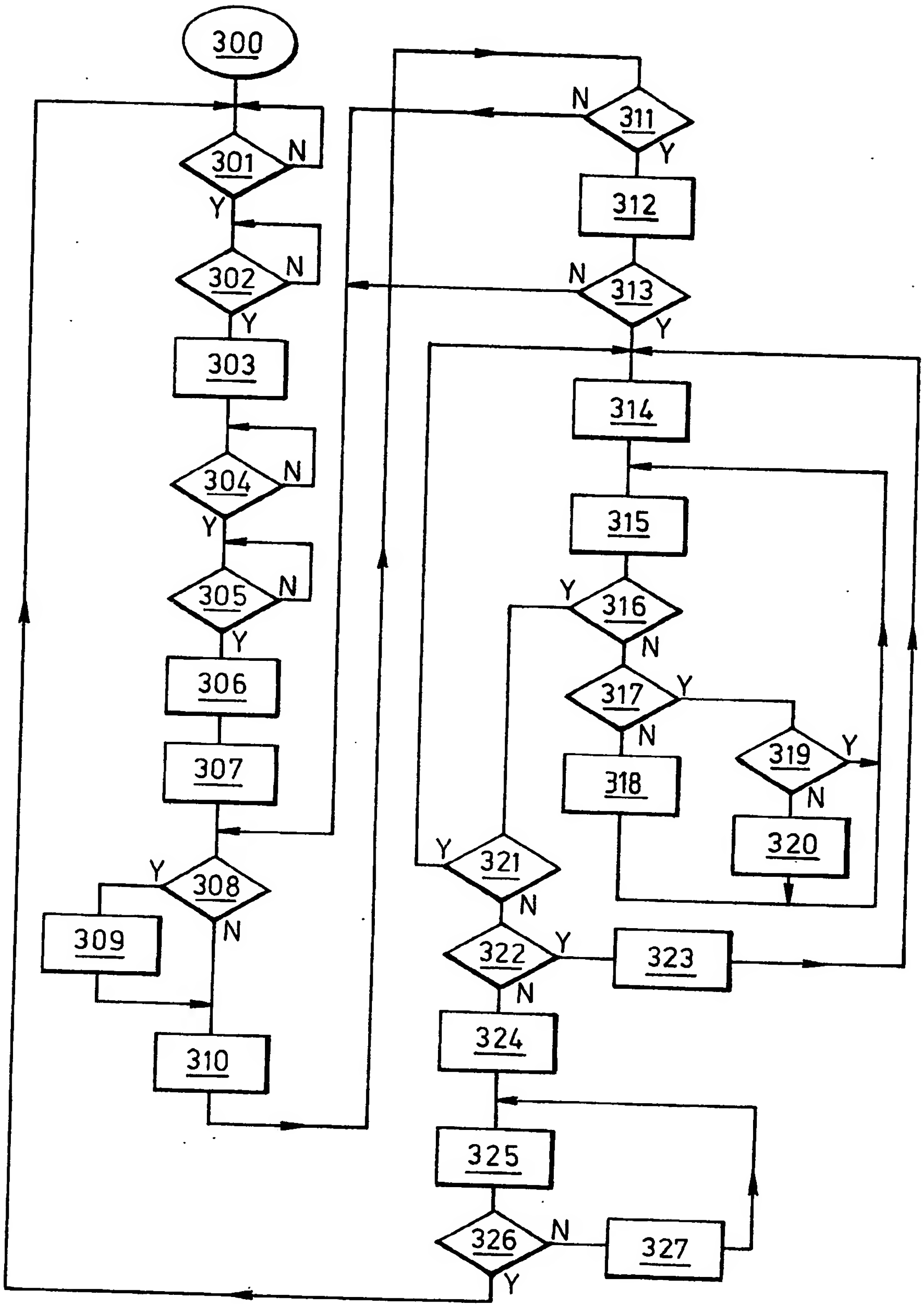
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Fig. 3.

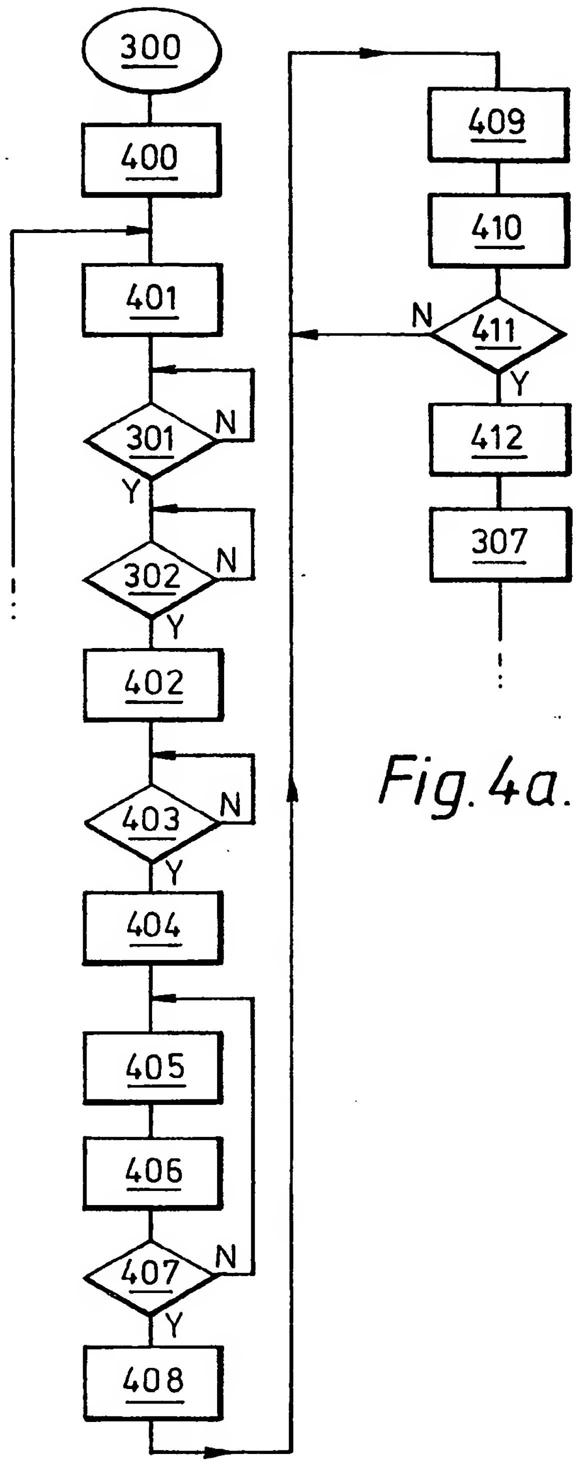
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Fig. 4a.

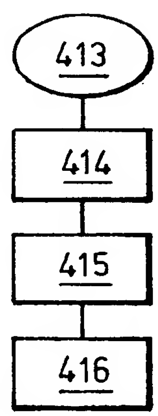
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Fig. 4b.

SPECIFICATION

Meth d and apparatus f r measuring the range and/ r radial vel city of a moving target

This invention relates to a method of and apparatus for measuring the range and/or radial velocity of a moving target.

Frequency-modulated continuous wave radar systems normally comprise a variable frequency oscillator the output of which is coupled to an aerial, means for repeatedly sweeping the output frequency of said oscillator between first and second values, a mixer circuit to a first input of which the output of said oscillator is coupled and to a second input of which an aerial is coupled, and a signal processing arrangement to an input of which the output of the mixer circuit is coupled. If the oscillator output signal transmitted by the aerial should be reflected back by a stationary target and fed to the second input of the mixer, and if the sweeps of the oscillator output frequency are linear, the mixer produces an output beat frequency signal the (constant if sweep end effects are neglected) frequency of which is proportional to the target range. In such systems the signal processing arrangement, for example a multiple filter, analyses the mixer output signal into its component frequencies to provide a read-out indicative of the various ranges at which reflecting targets are present. If on the other hand a given target is moving towards or away from the system the relevant output frequency of the mixer will gradually decrease or increase respectively. Moreover, if the sweeps of the output frequency of the oscillator are in an upward direction the relevant mixer output frequency will in these circumstances be lower or higher, respectively, at any given time then it would be if the target were stationary at the same range, because the frequency of the return signal will be higher or lower, respectively, than it would otherwise be, due to the Doppler effect. Such a system could be arranged to distinguish between a stationary target at a given range and a moving target at a different range by observing the relevant output frequency of the mixer over a period of time which is sufficient to allow the change in frequency with target range to become apparent. However, such a period of time can be considerable, particularly with relatively slowly-moving targets, which makes the use of such a method impracticable.

If, instead of repeatedly sweeping the oscillator frequency in an upward direction, sweeps in a downward direction are employed then, if a target is moving towards or away from the system, the mixer output frequency will, due to the Doppler effect, be higher or lower, respectively, then it would be if the target were stationary at the same range, i.e. it will be shifted in the opposite sense to the shift occurring with sweeps in the upward direction. Thus sweeping the oscillator frequency first in one direction and then in the other and averaging the frequencies of the two resulting output signals from the mixer corresponding to a target enables, on the face of it, the effects of the Doppler shifts on the apparent range of the target to be eliminated (although this becomes increasingly difficult for higher values of Doppler shift, i.e. Doppler shifts which are sufficiently large to become comparable with the output frequency of the mixer which would be obtained for a stationary target at the same range). This fact is known (see, for example, the book "Radar Handbook" edited by M.L. Skolnik, page 16-26 (1970)). If instead of averaging the spectral components lying within each of successive frequency ranges for the two sweeps their differences were calculated then the result would, on the face of it, be representative of the radial velocity of the target (towards or away from the system). This fact is also known (see, for example, page 83 of the book "Introduction to Radar Systems" by M.L. Skolnik, published by McGraw Hill, 1980). However, in practical situations there is a great deal of "clutter" in the return signals, with the result that it is not easy to decide which spectral components constitute a related pair, i.e. relate to the same target, and even which spectral components form part of a related pair at all. (An incorrect choice results in indication of a moving target having given range and velocity characteristics where in fact this target might not exist, two stationary targets or a moving target having different range and velocity characteristics being present instead).

Published patent application EP-A-099160 (PHB 32898) discloses a way of mitigating this disadvantage. More specifically said application discloses a moving target indication system comprising a variable-frequency oscillator the output of which is coupled to an aerial, means for repeatedly sweeping the output frequency of said oscillator in alternating senses between first and second values, a mixer circuit to a first input of which the output of said oscillator is coupled to a second input of which an aerial is coupled, and a signal storage and processing arrangement to an input of which the output of the mixer circuit is coupled, said signal storage and processing arrangement comprising means for producing an output signal which is representative of the waveforms (if any) which would be obtained by subtracting from each other the input waveforms to said arrangement arising from sweeps of the oscillator frequency between said first and second values in one sense and the input wav forms to said arrangement arising from sweeps of the oscillator frequency between said first and second values in th other sense after the latter input waveforms have been put into tim -reversed form. In such a system each resulting difference waveform is, for a single reflecting target, in the form of an amplitude-modulated carrier which is always present exc pt when the radial velocity of the target relative to the system is zero and the frequency of which is constant (neglecting sweep end effects) and corresponds to the range of the target. The modulation contains velocity information about the target. If the difference between the first and second values is much less than the first value, then the modulation will be of substantially constant

frequency. Thus each moving target gives rise to only a single band of spectral compon nts in the difference waveform, rather than a pair of bands of components. However, it has been found that such a system is rather difficult to put into practice because it entails the imp sition of v ry stringent requirem nts on the gr up delay characteristics of the necessary circuitry. It is accordingly an object of the present invention to provide an alternative way of mitigating the aforesaid disadvantage which need not entail the imposition of such stringent requirements.

The invention provides a method of measuring the range and/or radial velocity of a moving target, said method comprising the steps of (a) transmitting a radio-frequency signal the frequency of which repeatedly sweeps in one sense from a first value to a second value and in the other sense from a third value to a fourth value, (b) mixing received reflections of said signal from the target with the transmitted signal to produce beat-frequency signals, (c) determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the beat-frequency signals which arise from successive sweeps of the frequency of the transmitted signal from the first value to the second value, (d) determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the beat-frequency signals which arise from successive sweeps of the frequency of the transmitted signal from the third value to the fourth value, and (e) determining the range and/or radial velocity of the target from a frequency determined in step (c) and a frequency determined in step (d).

It should be noted that the aforesaid published application EP-A-099160 also discloses a moving target indication system comprising a variable-frequency oscillator the output of which is coupled to an aerial, means for repeatedly sweeping the output frequency of said oscillator from a first value to a second value, a mixer circuit to a first input of which the output of said oscillator is coupled and to a second input of which an aerial is coupled, and a signal storage and processing arrangement to an input of which the output of the mixer circuit is coupled, said signal storage and processing arrangement comprising means for producing an output signal which is representative of the waveforms (if any) which would be obtained by substracting from each other the input waveforms to said arrangement arising from successive sweeps of the oscillator frequency from said first value to said second value. However, in contradistinction to what is implied in said application, the difference waveform which results does not, for a single moving reflecting target, contain a single band of spectral components the frequency of which corresponds to the range of the target, but rather a single band of spectral components the frequency of which is Doppler-shifted with respect to that frequency. Thus such a system suffers from the same range-velocity ambiguity as was discussed hereinbefore. However, it has now been recognized that performing such a technique both for sweeps in the oscillator frequency from the first value to the second value, and also for sweeps from the third value to the fourth value before carrying out frequency averaging and/or frequency differencing operations on pairs of spectral components as discussed hereinbefore can make decisions on which bands of spectral components constitute a related pair much more easy because, in the ideal case, the spectrum actually analysed will no longer contain components which arise from stationary targets.

In order to facilitate calculation of the range and/or velocity of the target from a pair of determined frequencies preferably the said first and fourth values are substantially the same, and the said second and third values are substantially the same. For the same reason preferably the difference between the first and second values is substantially equal to the difference between the third and fourth values and each sweep is substantially linear and of the same duration. Preferably too the frequency of the radio-frequency signal repeatedly sweeps first twice in the one sense and then twice in the other sense. The absence of any of these preferred features may necessitate the inclusion in such a calculation of correction terms which would otherwise be absent.

If more than one frequency is determined in step (c) and more than one frequency is determined in step (d) preferably (i) pairs of a frequency determined in step (c) and a frequency determined in step (d) are provisionally formed for each such two frequencies the difference between which is less than a predetermined amount, (ii) each provisional pair which does not include a frequency which is also included, determined in the same step (c) or (d), in another different provisional pair is confirmed, and (iii) any other provisional pair which includes a frequency which is also included, determined in the same step (c) or (d), in a confirmed pair is eliminated, after which, if provisional pairs still remain, steps (ii) and (iii) are repeated until no more are eliminated, step (e) being performed on each pair confirmed in a step (ii). Performing such a procedure can be a very efficient way of determining which pairs of frequencies relate to the same moving targets.

It may be that some provisional pairs cannot be confirmed or eliminated by the above procedure, at least initially. If this is th case an estimat may be made on the basis of amplitude as to which of the remaining provisional pairs of frequencies relate to the same moving target. To this end, when n more provisional pairs are eliminated but at least one provisional pair remains, (iv) that remaining provisional pair the amplitudes of the components of which are most nearly the same may be confirmed, and (v) any other provisional pair which includes a frequency which is also included, determined in the same step (c) or (d), in the pair just confirmed may be eliminated, after which, if at least one provisional pair still remains steps (ii) and (iii) may be repeated until no m re provisional pairs are eliminated.

In order to facilitate the us of digital techniques the steps (c) and (d) may each be performed by pe-

riodically sampling the beat-frequ ncy signal which arises from a given sweep of the transmitted signal in the rel vant sense and storing the samples thus taken, correspondingly periodically sampling the beat-frequency signal which arises from th next sweep of the transmitted signal in the relevant sense, calculating the differences between the corresponding samples taken for the two sweeps, and performing a Fast Fourier Transform on the differences thus calculated.

The invention also provides apparatus for measuring the range and/or radial velocity of a moving target, comprising a variable-frequency oscillator the output of which is coupled to an aerial, means for repeatedly sweeping the output frequency of said oscillator in one sense from a first value to a second value and in the other sense from a third value to a fourth value, a mixer circuit to a first input of which the output of the oscillator is coupled and to a second input of which an aerial is coupled, and a signal storage and processing arrangement to an input of which the output of the mixer circuit is coupled, said signal storage and processing arrangement comprising means for determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the input waveforms to said arrangement arising from successive sweeps of the oscillator frequency from the first value to the second value, for determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the input waveforms to said arrangement arising from successive sweeps of the oscillator frequency from the third value to the fourth value, and determining the range and/or radial velocity of the target from a frequency of a first-mentioned said spectral component and the frequency of a second-mentioned said spectral component.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings in which:

Figure 1 is a block diagram of a first embodiment,

Figures 2a and *2b* show a possible construction for part of the embodiment of Figure 1 in detail,

Figure 3 is a flow chart relating to the operation of part of the embodiment of Figure 1, and

Figures 4a and *4b* are flow charts relating to an alternative to the construction shown in Figure 2.

In Figure 1 apparatus for measuring the range and/or radial velocity of a moving target comprises a variable-frequency (in this case voltage-controlled) RF oscillator 1 which operates, for example, in the gigahertz range and the output 2 of which is coupled to an aerial 3 via a circulator 4. Part of the output signal of the oscillator is taken off by means of a directional coupler 5 and fed to a first input 6 of a mixer circuit 7. The aerial 3 is coupled to a second input 8 of the mixer circuit 7 via the circulator 4. The output 9 of the mixer circuit 7 is coupled to an input 70 of a signal storage and processing arrangement 71 via an amplifier 12. The arrangement 71 comprises a signal sampling, storage and differencing circuit 11 to an input 10 of which the input 70 is connected, a Fast Fourier Transform calculating circuit 15 (examples of which are known) to an input 14 of which the output 13 of the circuit 11 is coupled, and a suitably programmed computer 100 part of an input port 101 of which is connected to the multi-bit output 16 of the circuit 15. Computer 100 has an output port 102 which constitutes the output of the arrangement 71. A control input 46 of circuit 15 is fed from a further output 45 of circuit 11. A frequency control input 17 of the oscillator 1 is fed from the output 18 of a signal generator 19 which generates an output voltage waveform each complete repetition period of which comprises two consecutive substantially linear sweeps in a given sense from a first value to a second value followed by two consecutive linear sweeps in the other sense from a third value to a fourth value, where the third and fourth values are preferably substantially equal to the second and first values respectively. The durations of the upward sweeps are all the same, as are the durations of the downward sweeps. Further outputs 20, 120 and 220 of generator 19 are coupled to a control input 21 of the circuit 11 via a coupling 47, to a further single-bit portion of the input port 101 of computer 100 via a coupling 147, and to another further single-bit portion of the input port 101 of computer 100 via a coupling 247, respectively.

In operation the aerial 3 is fed by oscillator 1 with a carrier wave which is frequency-modulated by the output signal of generator 19; the output frequency of oscillator 1 repeatedly and linearly sweeps twice in the upward direction from a first to a second value which lie in the gigahertz range and which may be, for example, 30MHz different from each other, and twice in the downward direction from a third to a fourth value which also lie in the gigahertz region and may again be, for example 30MHz different from each other. It will be assumed that the first value F is equal to the fourth value, that the second and third values are equal to each other, and that all sweep durations are the same and are equal to T. T may be equal to, for example 80 μS. If the electromagnetic signal from aerial 3 should be reflected back to the aerial by a stationary object at a range R then, as is known in the context of FM radar systems, a beat or difference frequency signal results at the output 9 of mixer 7, the frequency of this signal being equal to $2Ra/c$ where a is the rate of change of the output frequency of oscillator 1 and c is the velocity of light. Thus, if the circuit 11 were replaced by a direct connection between its input 10 and its output 13 the Fast Fourier Transform calculating circuit 15 would produce an output signal indicating a spectral component at a frequency $2Ra/c$ under these circumstances. If, on the other hand, the object is not stationary but is moving away from the aerial 3 with a velocity v then, the other circumstances being the same, the output signal of the circuit 15 would, for upward sweeps of the output frequency of oscillator 1, indicate a spectral component at the frequency $2Ra/c + 2\,Fv/c$ (neglecting second order effects) wher F is the output frequency of oscillator 1 at the start of the upward sweeps. Similarly, for downward sweeps of the output frequency of oscillator 1, the output signal of the circuit 15 would indicate a spectral component at the

frequency 2Ra/c-2Fv/c. It will be seen that the (D ppler shift) term 2Fv/c is of the opp sit sign so, as pointed out hereinbefore, the actual range and radial velocity of the target could be determined from the average of, and the difference between, respectively, these two frequencies. However, as also p inted out hereinbefore, this is difficult to do in the presence of the inevitable clutter and, as the arrangement is required to measure characteristics only of moving objects the circuit 11 is in fact included, this circuit being constructed to produce a signal at its output 13 which is representative of the waveforms (if any) which would be obtained by subtracting from each other the waveforms applied to its input 10 arising from sweeps of the output frequency of oscillator 1 in one sense and by subtracting from each other the waveforms applied to its input 10 arising from sweeps of the output frequency of oscillator 1 in the other sense. More particularly, the circuit 11 is constructed to take and store successive samples of the waveform applied to its input 10 arising from the first sweep of each pair of sweeps of the output frequency of oscillator 1 in the same sense and, when a waveform is applied to its input 10 arising from the second of the corresponding pair of sweeps in the output frequency of oscillator 1 in the same sense, to also take successive samples of this latter waveform and subtract from them the stored samples of the waveform which arose from the immediately preceding frequency sweep in such manner that each sample so subtracted arose from the same output frequency of oscillator 1 being applied to input 6 of mixer 7 as does the sample from which it is being subtracted. This it does for sweeps in both senses and therefore, in effect, produces (in the form of samples) output waveforms which are equal to any difference there might be between the waveforms applied to its input 10 for successive similarly directed sweeps of the output frequency of oscillator 1 in either sense. That this results in a reduction (in the ideal case in elimination) of any contribution there would otherwise be to the input signal to circuit 15 arising from stationary targets, and hence from clutter, can be demonstrated as follows.

If R, *a*, T F and *c* have the meanings previously assigned to them, and *t* is time, then the output waveform of mixer 7 during the first sweep of a pair of upward sweeps of the output frequency of oscillator 1 can be written as

$$\sin 4\pi\ (R+vt)(F+at)/c$$

and the output waveform of mixer 7 during the second sweep of this pair can be written as

$$\sin 4\pi\ (R+vt+vT)(F+at)/c.$$

Standard trigonometrical manipulation gives the difference between these waveforms, i.e. the output signal of circuit 11, as

$$2\cos 2\tfrac{\pi}{c}\,(F+at)\,(2R+2vt+vT)\,\sin 2\tfrac{\pi}{c}\,(F+at)vT$$

i.e. an amplitude-modulated carrier wave which, if second-order terms are neglected, has a frequency of 2aR/c + 2vF/c. Similarly, the output waveform of mixer 7 during the first sweep of a pair of downward sweeps of the output frequency of oscillator 1 can be written as

$$\sin 4\pi\ (R+vt)(F+aT-at)/c$$

and the output waveform of mixer 7 during the second sweep of this pair can be written as

$$\sin 4\pi\ (R+vt+vT)(F+aT-at)/c.$$

Standard trigonometrical manipulation gives the difference between these waveforms, i.e. the output signal of circuit 11, as

$$2\cos 2\tfrac{\pi}{c}\,(2R+2vt+vT)\,(F+aT-at)\sin 2\tfrac{\pi}{c}\,(F+aT-at)\,(vT)$$

i.e. an amplitude-modulated carrier wave which, if second-order terms are neglected, has a frequency of − 2aR/c+2vF/c, or 2aR/c−2vF/c if it is arranged that aR is greater than vF, which can always be done by choosing a sufficiently large value for *a*. It will be noted that the amplitude modulation (sine) term in each of the above expressions for the difference waveform includes the term "*v*". The difference waveform therefore does not, at least in the ideal case, contain spectral components corresponding to stationary reflecting targets, as required. Otherwise, i.e. for moving targets, the frequencies of the corresponding spectral components are the same as those in the output signal of mixer 7, and can therefore be paired and us d to calculate the ranges and/or velocities of the corresponding targets, a task which is made much more easy due to the fact that the spectra, at least in the ideal case, no longer contain contributions from stationary targets. The spectra are analysed by the Fast Fourier Transform circuit 15, the output signal of which, after each complete difference waveform is applied to it, indicates a well-defined band of spectral comp n nts around the Doppler-shifted frequency corresponding to the distance of the reflecting object if and only if that object has a velocity component to or from the aerial 3,

the Doppler shifts being rev rsed for each succeeding differ nce waveform. These bands are paired and the corresponding target ranges and/or velocities calculated from the average frequency of each pair and/ or the difference between the frequencies of each pair, respectively, by means of the computer 100. An example of how this may be done will be described below.

Figur 2 shows a possible construction for the signal sampling, storage and differencing circuit 11 and generator 19 of Figure 1, the various inputs and outputs of these two components being given the same reference numerals in the two Figures. In Figure 2 the generator is formed by a pair of cascade-connected 4-bit counters 22 and 23 the clock inputs CLK of which are fed from the output of a clock pulse generator 24. The "carry" output CY of counter 22 is connected to the "count enable trickle" and "count enable parallel" inputs ET and EP respectively of counter 23 and the terminals ET and EP of counter 22 are connected to logic "1" (approximately plus 5 volts) as are the (active low) "load" (LD) and "clear" (CLR) inputs of both counters. Neither the most significant bit output QD nor the carry output CY of counter 23 is used, so the counters 22 and 23 together form a 7-bit counter 22, 23. The most significant bit output QD of counter 22 and the three least significant bit outputs QA, QB and QC of counter 23 are coupled to the clock input CLK of a J-K flip-flop 25 via a NAND gate 26. The J and K inputs of flip-flop 25 are connected to logic "1" as is its (active low) reset input R so that it operates in the "toggle" mode; its Q-output changes state each time its clock input changes from high to low, i.e. each time the count in counter 22, 23 becomes 120 (0001111). The Q and $\overline{Q}$ outputs of flip-flop 25 are connected to the non-inverting and inverting inputs respectively of an operational amplifier 150 and to the inverting and non-inverting inputs respectively of an operational amplifier 151. The output of amplifier 150 is connected to the gates of n-channel insulated-gate field-effect transistors 152 and 152 and the output of amplifier 151 is connected to the gates of n-channel insulated-gate field-effect transistors 154 and 155. The sources of the transistors 153 and 154 are connected to the drains of the transistors 152 and 154 respectively, and their drains are connected to a potential $+V_{max}$ and to the +5V rail respectively. The sources of the transistors 152 and 155 are connected to −5V and to ground (OV) respectively. The common point of the source of transistor 154 and the drain of transistor 152 is connected to the input of an integrator circuit. This integrator circuit comprises an operational amplifier 156 to the inverting input of which said common point is connected via a resistor 157 and the output of which is connected to the inverting input via the parallel combination of a capacitor 159 and the source-drain path of an n-channel insulated-gate field-effect transistor 160. The non-inverting input of amplifier 156 is connected to the common point of the source of transistor 153 and the drain of transistor 155 and its output is connected to the terminal 18 of Figure 1. Thus, when the Q-output of flip-flop 25 is high (logic "1") the non-inverting input of amplifier 156 is connected to V_{max} via transistor 153 and resistor 157 is connected to −5V via transistor 152. Conversely, when the Q-output of flip-flop 25 is low (logic "0") the non-inverting input of amplifier 156 is connected to ground (OV) via transistor 155 and the resistor 157 is connected to +5V via transistor 154. The output 120 of Figure 1 is fed from the $\overline{Q}$ output of flip-flop 25.

The most significant bit output QD of counter 22 and the two least significant bit outputs QA and QB of counter 23 are also coupled to the (active low) trigger input $\overline{A}1$ of a monostable multivibrator 80 via a NAND gate 126. Multivibrator 80, which is provided with a timing capacitor 81, is therefore triggered each time the output of gate 126 changes from high to low, i.e. each time the count in counter 22, 23 becomes 56 or 120 (0001110 or 0001111). Multivibrator 80 may be of the type 74121, in which case its other active low trigger input A2 and its active high trigger input B may be connected to logic "1" as shown. The non-inverting and inverting outputs Q and $\overline{Q}$ of multivibrator 80 are connected to the non-inverting and inverting inputs respectively of an operational amplifier 82 the output of which is connected to the gate of the transistor 160. Thus, each time the count in counter 22, 23 becomes 56 or 120 multivibrator 80 produces a short output pulse which causes transistor 160 to momentarily conduct and restore the potentials on the inverting input and the output of amplifier 156 to that on its non-inverting input.

The combined effect of the components 25, 26, 80-82, 126, 150-160 is therefore to cause the voltage at terminal 18 to start to ramp either in a positive direction from ground potential or in a negative direction from $+V_{max}$ each time the count in counter 22, 23 becomes 120 and consequently changes over flip-flop 25 and triggers multivibrator 80, to return to ground potential or $+V_{max}$ respectively and start a second similar ramp when the count in counter 22, 23 next becomes 56 and consequently triggers multivibrator 80, then to describe two ramps of the other kind, then to describe two ramps of the first kind, and so on as required. The voltage $+V_{max}$ is chosen to be as accurately as possible equal to the voltage reached by terminal 18 at the ends of the positive-going ramps thereat. In order to minimize transients which are liable to occur at the output of amplifier 156 each time flip-flop 25 is triggered, it is ensured by a suitable choice of components that each time this occurs it has actually chang d state when multivibrator 80, which is nominally triggered at the same tim , attains its astable state. The logic level on output 120 indicates to the computer 100 of Figure 1 which of the two kinds of ramp is currently being undertaken.

The outputs QD of counter 22 and QA and QB of counter 23 are also connected to address bit inputs A0, A1 and A2 respectively of two random access memories (RAMs) 33 and 34 which each comprise sixteen 4-bit storage locations. Th RAMs 33 and 34 thus effectively constitute a single RAM comprising sixteen 8-bit storage locations addressed by the relevant three outputs of counter 22, 23 although, as the address bit inputs A3 of the RAMs 33 and 34 are both connected t ground, only eight of these locations

are actually used.

A NAND gate 35 is fed from the outputs QA and QC of the counter 22 directly and from the output QB thereof via an inverter 36. Thus the output of gate 35 is low each time the digital number at these outputs QA, QB and QC is five (101). A NAND gate 37 is fed from the output of gate 35 via an inverter 38 and from the output QC of count r 23 via an inverter 39, and itself feeds the (active low) write-enable inputs WE of the RAMs 33 and 34. Thus RAMs 33 and 34 are fed with a write-enable pulse at an instant (when the digital number at outputs QA, QB and QC is five) within each period during which the address applied to their address inputs has taken on a new value while the first of each pair of ramps in the same sense is occurring at terminal 18 but not while the second of each pair of ramps in the same sense is occurring thereat. In other words the RAM locations are written into while the first of each pair of ramps is occurring and read out while the second of each pair is occurring.

The output QC of counter 23 also feeds the output 220 of Figure 1 to indicate to computer 100 when a new set of spectral data is present on the output 16 of FFT-calculating circuit 15.

The data inputs DO-D3 of the RAMs 33 and 34 are fed from respective bit-outputs D1-D8 (where D8 is the most significant bit) of an analog-to-digital converter 40 the analog input I of which is connected to the terminal 10 of Figure 1. The "convert command" input CV of converter 40 is fed from the output QC of counter 22, so that a new conversion is carried out just before each instant that the output of gate 35 goes low (and RAMs 33 and 34 are written into during the first of each pair of ramps in the same sense at terminal 18). Converter 40 is a so-called "flash converter" and, each time a convert command is applied to it it takes in a sample of the signal at its input 10 and then outputs the converted sample taken immediately previously, so that its output signal corresponds, at any given time, not to the immediately preceding sample taken but to the sample which preceded it. The RAMs 33 and 34 are always operative, their (active low) chip-select inputs $\overline{CS}$ being connected to ground, and their inverting data outputs $\overline{O0}$-$\overline{O3}$ are connected to respective first bit inputs A4-A1 of full adders 41 and 42 respectively. The second bit inputs B4-B1 of the adders 41 and 42 are fed from respective ones of the bit outputs D8-D1 of the converter 40, and the carry input $\overline{C1}$ of the adder 41 is fed from the carry output CO of the adder 42. The carry input C1 of the adder 42 is connected to logic "1" (the adders 41 and 42 operate in the active low or negative logic mode). Because of the inversion occurring in the RAMs 33 and 34 the 8-bit number appearing at any time at the outputs $\Sigma 4-\Sigma 1$ of the adders 41 and 42 is equal to the difference between the number currently appearing at the output D8-D1 of converter 40 and the eight-bit number which was previously written into the currently addressed storage location in the RAM 33, 34. The outputs $\Sigma 4-\Sigma 1$ are fed to the output 13 of Figure 1 via a positive edge triggered multiple D-type flip-flop or register 43 the (active low) output-enable terminal DE of which is connected to ground and the clock input CLK of which is fed from a NOR gate 44. The NOR gate 44 is fed from the outputs of the gate 35 and the inverter 39. Thus, if the time-lag which has been incorporated to allow for the operation of converter 40 is ignored, effectively information is written into the register 43 and a "data available" signal (for use by the Fast Fourier Transofrm calculating circuit 15 of Figure 1) appears at an output 45 each time the digital number at the outputs QA, QB and QC of counter 22 becomes five while the locations in RAM 33, 34 are being addressed during the occurrence of the second ramp of each similarly-directed pair at terminal 18 (in which situation write-enable pulses are not applied to the RAM 33, 34) but not while these locations are being addressed during the occurrence of the first ramp of each pair (in which situation write-enable pulses are applied to the RAM 33, 34). Because the voltage waveform at the output 18 is derived in the manner described from the output of the counter 22, 23, samples of the signal at input 10 are written into the RAM 33, 34 during the first of each two similarly-directed ramps at the output 18, and hence during the first of each two sweeps of the output frequency of oscillator 1 of Figure 1 in the same sense, and these samples are read out, subtracted from samples of the new signal at input 10, and written into the register 43 during the second of each two similarly-directed ramps at output 18, and hence during the second of each two sweeps of the output frequency of oscillator 1 in the same sense. Thus during every second sweep of the output frequency of oscillator 1 a succession of (eight) digital signals appear at the output 13, these samples being measures of the difference between samples of the waveform currently appearing at the input 10 and corresponding samples of the waveform which appeared at the input 10 during the immediately preceding similarly directed sweep of the output frequency of oscillator 1, as required.

The clock generator 24 may, for example, have an output frequency of 800KHz, giving a sampling rate in A/D converter 40 of 100K samples per second, durations of the rising and falling ramps at output 18 of 80μS each, and an average data rate in the Fast Fourier Transform calculating circuit 15 of 50K bytes/sec (in 80μS bursts at 100K bytes/sec). In this case a low-pass filter having a cut-off frequency of 50KHz should bviously be included between the output 9 of mixer 7 and the input 10 of arrangement 11.

The various components of Figur 2 may be of the following types or values:-

Counters 22 and 23	74LS163
RAMs 33 and 34	7489
Adders 41 and 42	74283
Register 43	74LS374
Converter 40	TDC1007
Inverters 36, 38, 39	Each 1/6 of 7404
NAND gate 26	1/2 of 7420
NAND gate 35	1/3 of 7410
NOR gate 37	1/4 of 7400
NOR gate 44	1/4 of 7402
JK flip-flop 25	1/2 of 7473
Amplifiers 82, 150, 151, 156	LM 356
Resistor 157	100K ohms.
Capacitor 81	470 pF.
Capacitor 159	10nF.
Multivibrator 80	74121
Transistors 150-155, 160	BSV81

If desired the number of samples taken in each frequency sweep may be increased by increasing the size of the counter 22, 23 (increasing the number of bits between outputs QD of counter 22 and QB of counter 23) to generate more addresses and increasing the number of locations used in RAM 33, 34 accordingly (if necessary adding more RAM). If this is done the NAND gates 26 and 126 will obviously each have to be provided with a further input corresponding to each further address bit employed and connected to the relevant output of counter 22, 23.

Each time the oscillator 1 of Figure 1 has completed the second frequency sweep of a pair of similarly-directed frequency sweeps, and the circuit 11 has applied a complete set of samples of the resulting difference waveform to FFT-calculating circuit 15, resulting in circuit 15 producing a signal at its multi-bit output 16 indicative of the spectral components present in the difference waveform, the output QC of counter 23 changes from high to low, signalling to computer 100 to process the output signal of circuit 15. Computer 100 is programmed to perform the operations set forth in the flow chart of Figure 3, in which it has been assumed that the set state (Q=1) of flip-flop 25 in Figure 2 corresponds to an upward sweep in the output frequency of oscillator 1. The various boxes of Figure 3 have the following significances:

300 - Start

301 - Is output QC of counter 23 (output 220 of Figures 1 and 2) high?

302 - Is output QC of counter 23 low? (Has new pair of similarly-directed frequency sweeps of output signal of oscillator 1 just started).

303 - Read output signal of circuit 15 and store frequencies and amplitudes of spectral components the amplitudes of which exceed a predetermined threshold, these values being classified in accordance with the logic level on output $\overline{Q}$ of flip-flop 25 (output 120 in Figures 1 and 2). $\overline{Q}$=1 indicates that data relates to upward frequency sweeps from oscillator 1 and $\overline{Q}$=0 indicates that data relates to downward frequency sweeps.

304 - Is output QC of counter 23 high?

305 - Is output QC of counter 23 low?

306 - Read output signal of circuit 15 and store frequencies and amplitudes of spectral components the amplitudes of which exceed a predetermined threshold, these values being classified in accordance with logic level on output Q of flip-flop 25.

307 - Set variables m and n = 1.

308 - Is the difference between the mth lowest frequency stored in operation 303 and the nth lowest frequency stored in operation 306 less than a predetermined amount? (Is it possible that the difference between these frequencies is accounted for by Doppler shifts of the return signal from a single moving target having a feasible radial velocity relative to the arrangement?

309 - Store these frequencies together with the corresponding amplitudes and the corresponding classifications as a possibl related pair.

310 - Increment n.

311 - Is n greater than the number of frequencies stored in operation 306?

312 - Set n = 1. Increment m.

313 - Is m greater than the number of frequencies stored in peration 303?

314 - Set variable p = 0.

315 - Increment p.

316 - Does p exceed the number of possible related pairs stored in operation 309 which have not yet been confirmed as a related pair or eliminated

317 - Does the pth possible related pair t have been stored in operation 309 which has neither been confirmed as a related pair nor eliminated include a component, classified in accordance with the Q-output of flip-flop 25 being logic "1", also occur, similarly classified, in any different p ssible related pair stored in operation 309?

318 - Designate the relevant possible relat d pair as a confirmed related pair and eliminate all other possible related pairs containing either of the two frequencies of the now confirmed related pair provided that these frequencies have the same classification as the corresponding frequency in the now confirmed related pair.

319 - Does the pth possible related pair to have been stored in operation 309 which has neither been confirmed as a related pair nor eliminated include a component, classified in accordance with the $\overline{Q}$-output of flip-flop 25 being logic "0", also occur, similarly classified, in any different possible related pair stored in operation 309?

320 - Designate the relevant possible related pair as a confirmed related pair and eliminate all other possible related pairs containing either of the two frequencies of the now confirmed related pair provided that these frequencies have the same classification as the corresponding frequency in the now confirmed related pair.

321 - Have any possible related pairs been confirmed as a related pair since 314 was last performed?

322 - Are there any remaining possible related pairs which have not yet been confirmed or eliminated?

323 - Find that remaining possible related pair the amplitudes of the two components of which are most nearly the same. Designate that possible related pair as a confirmed related pair and eliminate all other possible related pairs containing either of the two frequencies of the now confirmed related pair provided that these frequencies have the same classification as the corresponding frequency in the now confirmed related pair.

324 - Set variable $q = 0$.

325 - Increment q.

326 - Is q greater than the total number of confirmed related pairs?

327 - Calculate range and radial velocity of a moving target from the mean value of, and the difference between, respectively, the component frequencies of the qth confirmed related pair, and store results.

After the output signal of FFT circuit 15 relating to two sweeps of the output frequency of oscillator 1 in one direction has been stored in operation 303, and also the output signal of FFT circuit 15 relating to two sweeps of the output frequency of oscillator 1 in the other direction has been stored in operation 306, computer 100 first finds all the possible pairs of spectral components which could feasibly relate to the same moving target (steps 307-313). It then takes these possible related pairs one by one and confirms as related pairs those containing at least one component which does not occur, derived from sweeps of the output frequency of oscillator 1 in the same direction, in any other different possible related pair. It also eliminates any other possible related pair which contains a component corresponding to a component in the now confirmed related pair provided that that component is derived from sweeps of the output frequency of oscillator 1 in the same direction. It continues to do this, starting at the first remaining possible pair again each time all possible pairs have been treated, until no more pairs are confirmed (steps 314-321). If after this there are still non-confirmed and non-eliminated possible related pairs remaining (test 322) these remaining pairs are confirmed in the order of which the amplitudes of the two components are most nearly the same, each time such a confirmation occurs any still remaining possible related pair which contains a component which is the same as a component of the just-confirmed pair and derived from sweeps of the oscillator output frequency in the same direction being eliminated (step 323). Each time a pair has been confirmed in this way the program returns to step 314, as there may now be another possible related pair which contains at least one component which does not occur, derived from sweeps of the output frequency of oscillator 1 in the same direction, in any other different possible related pair. When all pairs have finally been confirmed or eliminated the ranges and radial velocities of the moving targets corresponding to the respective confirmed pairs are calculated and stored (steps 324-327) after which the program returns to test 301, awaiting the production of a new output signal by FFT-calculating circuit 15. As set forth hereinbefore, if second-order effects are neglected the range R of a given target is c/4a times the sum of the magnitudes of the frequencies of the relevant pair of spectral components, and the velocity v of the target is c/4F times the difference between these magnitudes, where c is the velocity of light, a is the rate of change of the output frequency of oscillator 1, and F is the output frequency of oscillator 1 at the start of the upward sweeps. In general the second order effects will not sensibly affect the results.

Although as described the upward sweeps of the output frequency of oscillator 1 occur between the same limits as the downward sweeps this is n t essential, provided always that each pair of upward sweeps are between the same limits and each pair of downward sweeps are betwe n the same limits. It is not even essential that the upward and downward sweeps overlap. Moreover, the rate of change of the scillator frequency for the upward sweeps may be different to the rate of change for the downward sweeps and/or may vary in a predetermined manner during each sweep. Another possibility is that upward sweeps alternate with downward sweeps, provided that differencing circuit 11 always operates to determine the difference between pairs of output signals of mixer 7 resulting from sweeps in the same direction. Yet another possibility is to make the output frequency of scillator 1 pause at a given valu

for a given time between each sweep and the next (suitably blanking the mixer utput signal during these pauses). However, all these other possibilities will necessitate the making of corrections to the spectral components indicated by the FFT-calculating circuit 15 and/or corrections for non-linearities, so the sweep characteristics described are preferred.

In general the FFT-calculating circuit 15 will indicate the relative phases of the various spectral components, in addition to their frequencies and amplitudes. As this phase information is not used it is evident that circuit 15 may be replaced by a circuit which produces only frequency and amplitudes information, for example a filter bank the component filters of which have a common input and are provided with respective amplitude detectors at their outputs. Obviously if this is the case and the differencing circuit 11 produces output samples as described a digital-to-analogue converter will have to be included between it and the input of the filter bank. Such a converter can be dispensed with if the differencing circuit itself operates in an analogue manner, storing the first of each pair of output signals of mixer 7 in analogue form and then reading out and subtracting the stored signal from the second output signal of mixer 7 in synchronism with the apparatus of corresponding parts of this second output signal.

As an alternative to employing the construction of Figure 2 the functions of the signal sampling, storage and differencing circuit 11 of Figure 1 may be carried out by the computer 100, as may be the function of the Fast Fourier Transform calculating circuit 15. To this end the components 33-34, 37-39 and 41-44 of Figure 2 together with the circuit 15 of Figure 1 may be omitted, the portion of the input port 101 of Figure 1 which is connected to the output of circuit 15 may be connected directly to the output of A/D converter 40, and a low-transition-sensitive external interrupt input of computer 100 may be connected to the output of NAND gate 35. The computer 100 may include a RAM in the form of an array of thirty-two rows of nine single-bit storage locations provided with two row pointers, and be programmed to perform the sequence of operations shown in the flow chart of Figure 3 modified by replacing steps 300-307 by the steps shown in Figure 4a, and also to perform the interrupt routine shown in Figure 4b each time a high-to-low transistion occurs on its interrupt input. The various blocks of Figure 4a have the following significances:

300 - Start

400 - Disable external interrupt

401 - Set RAM row pointer 1 to zero

301 - Is output QC of counter 23 high?

302 - Is output QC of counter 23 low? (Has new frequency sweep of output of oscillator 1 just started?)

402 - Enable external interrupt

403 - Has RAM row pointer 1 passed row 31?

404 - Disable external interrupt. Reset RAM row pointers 1 and 2 to zero and eight respectively.

405 - Ignoring sweep direction-indicating bit subtract information in RAM row pointed to by pointer 1 from that in RAM row pointed to by pointer 2 and store result together with relevant sweep direction-indicating bit.

406 - Increment pointers 1 and 2.

407 - Does pointer 2 point to RAM row 16?

408 - Perform Fast Fourier Transform on the data stored in the eight previous steps 405 and store result together with relevant sweep direction-indicating bit.

409 - As 405.

410 - As 406.

411 - Does pointer 1 point to RAM row 16?

412 - Perform Fast Fourier Transform on the data stored in the eight previous steps 409 and store result together with relevant sweep direction-indicating bit.

(When the flow chart of Figure 3 is modified by replacing steps 300-307 by the above steps the references in the key to Figure 3 to the now non-existant operations 303 and 306 (in the descriptions of blocks 308, 311 and 313) should be taken as references instead to operations 408 and 412 respectively). Programs for performing Fast Fourier Transforms on groups of data representing samples of an input waveform are known per se.

The various blocks of Figure 4b constitute the interrupt routine with respect to the main program represented by the flow chart of Figure 3 modified by 4a, and have the following significances:-

413 - Start

414 - Ignoring the signal on coupling 247, read the information at the input port 101, i.e. the information at the output of A/D converter 40 together with the sweep direction-indicating bit on coupling 147 into the RAM row pointed to by point r 1.

415 - Increment RAM row pointer 1.

416 - Return.

Of course the functions f the components 22, 23, 26, 126, 35 and 36 of Figure 2 may also be performed by the computer 100 if desired.

As described, the two sets of samples of the output waveform of mixer 7 which are subtracted one from the other relate to respective ones of two adjacent similarly-directed sweeps of the output frequency of oscillator 1. This is not essential and they may be arranged to relate to, for example, the sec-

ond of two adjacent frequency sweeps in one direction and the first of the next two adjacent frequency sweeps in that direction, respectively. As a further xample they may each be derived fr m the suitably weighted summed version of th mixer output waveforms produced in response to several recent frequency sweeps in th relevant direction.

Because the circuits 11 and 15 of Figur 2 are essentially linear devices the order in which they process the output signal of mixer 7 may be reversed if desired. Thus, instead of calculating the differences between the corresponding samples of the output waveforms of mixer 7 in the time domain, and then calculating the Fast Fourier Transform of the result, the Fast Fourier Transforms of the output waveforms of mixer 7 for successive sweeps in the same direction may be calculated first, and then subtracted one from the other, resulting in the subtraction occurring in the frequency domain.

CLAIMS

1. A method of measuring the range and/or radial velocity of a moving target, said method comprising the steps of (a) transmitting a radio-frequency signal the frequency of which repeatedly sweeps in one sense from a first value to a second value and in the other sense from a third value to a fourth value, (b) mixing received reflections of said signal from the target with the transmitted signal to produce beat-frequency signals, (c) determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the beat-frequency signals which arise from successive sweeps of the frequency of the transmitted signal from the first value to the second value, (d) determining the frequencies of spectral components of the waveform (if any) which would be obtained by subtracting from each other the beat-frequency signals which arise from successive sweeps of the frequency of the transmitted signal from the third value to the fourth value, and (e) determining the range and/or radial velocity of the target from a frequency determined in step (c) and a frequency determined in step (d).

2. A method as claimed in Claim 1, wherein the said first and fourth values are substantially the same, and the said second and third values are substantially the same.

3. A method as claimed in Claim 1 or Claim 2, wherein the difference between the first and second values is substantially equal to the difference between the third and fourth values, and each sweep is substantially linear and of the same duration.

4. A method as claimed in any preceding Claim, wherein the frequency of the radio-frequency signal repeatedly sweeps first twice in the one sense and then twice in the other sense.

5. A method as claimed in any preceding Claim wherein, when more than one frequency is determined in step (c) and more than one frequency is determined in step (d), (i) pairs of a frequency determined in step (c) and a frequency determined in step (d) are provisionally formed for each such two frequencies the difference between which is less than a predetermined amount, (ii) each provisional pair which does not include a frequency which is also included, determined in the same step (c) or (d), in another different provisional pair is confirmed, and (iii) any other provisional pair which includes a frequency which is also included, determined in the same step (c) or (d), in a confirmed pair is eliminated, after which, if provisional pairs still remain, steps (ii) and (iii) are repeated until no more are eliminated, step (e) being performed on each pair confirmed in a step (ii).

6. A method as claimed in Claim 5 wherein, when no more provisional pairs are eliminated but at least one provisional pair still remains, (iv) that remaining provisional pair the amplitudes of the components of which are most nearly the same is confirmed, and (v) any other provisional pair which includes a frequency which is also included, determined in the same step (c) or (d), in the pair just confirmed is eliminated, after which, if at least one provisional pair still remains, steps (ii) and (iii) are repeated until no more provisional pairs are eliminated.

7. A method as claimed in any preceding Claim, wherein step (c) and step (d) are each performed by periodically sampling the beat-frequency signal which arises from a given sweep of the transmitted signal in the relevant sense and storing the samples thus taken, correspondingly periodically sampling the beat-frequency signal which arises from the next sweep of the transmitted signal in the relevant sense, calculating the differences between the corresponding samples taken for the two sweeps, and performing a Fast Fourier Transform on the differences thus calculated.

8. A method of measuring the range and/or radial velocity of a moving target, substantially as described herein with reference to the drawings.

9. Apparatus for measuring the range and/or radial velocity of a moving target, comprising a variable-frequency oscillator the output of which is coupled to an aerial, means for repeatedly sweeping the output frequency of said oscillator in one sense from a first value to a second value and in the other sense from a third value to a fourth value, a mixer circuit to a first input of which th output of the oscillator is coupled an to a second input f which an aerial is coupled, and a signal storage and processing arrangement to an input of which the output of the mixer circuit is coupled, said signal storage and processing arrangement comprising means for determining the frequencies of spectral c mponents of the waveform (if any) which would be obtained by substracting from each other th input waveforms to said arrangement arising from successive sweeps of the oscillator frequency from th first value to the second value, for determining the frequencies of spectral components of the waveform (if any) which would be ob-

tained by subtracting from each ther the input wavef rms to said arrangement arising from successive sweeps of the oscillator frequency fr m the third value to the fourth value, and determining th range and/or radial velocity of the target from a frequency of a first-mentioned said spectral c mponent and the frequency of a second-mentioned said spectral compon nt.

10. Apparatus as claimed in Claim 9, wherein the means for repeatedly sweeping the output frequency are such that the said first and fourth values are substantially the same, and the said second and third values are substantially the same.

11. Apparatus as claimed in Claim 9 or Claim 10, wherein the means for repeatedly sweeping the output frequency are such that the difference beween the first and second values is substantially equal to the difference between the third and fourth values and each sweep is substantially linear and of the same duration.

12. Apparatus as claimed in any of Claims 9 to 11, wherein the means for repeatedly sweeping the output frequency are arranged to sweep said frequency repeatedly first twice in the one sense and then twice in the other sense.

13. Apparatus as claimed in any of Claims 9 to 12, wherein the signal storage and processing arrangement comprises means for, when there is more than one said first-mentioned spectral component and more than one said second-mentioned spectral component, (i) provisionally forming pairs of a frequency of a said first-mentioned spectral component and a frequency of a said second-mentioned spectral component for each such two frequencies the difference between which is less than a predetermined amount, (ii) confirming each pair thus formed which does not include a frequency which is also included in another different provisional pair and is of a spectral component of the same type (first-mentioned or second-mentioned), (iii) eliminating any other provisional pair which includes a frequency which is also included in a confirmed pair and is of the said type, (iv) repeating operations (ii) and (iii) if provisional pairs still remain until no more are eliminated, and (v) determining the range and/or radial velocity of a target from each confirmed pair of frequencies.

14. Apparatus as claimed in Claim 13, wherein the signal storage and processing arrangement comprises means for, when no more provisional pairs are eliminated but at least one provisional pair still remains, (vi) confirming that remaining provisional pair the amplitudes of the components of which are most nearly the same, (vii) eliminating any other provisional pair which includes a frequency which is also included in the pair just confirmed and is of the same said type and, if at least one provisional pair still remains, repeating operations (ii) and (iii) until no more provisional pairs are eliminated.

15. Apparatus as claimed in any of Claims 9 to 14 wherein the signal storage and processing arrangement comprises signal sampling, storage and processing means for periodically sampling the input waveform to the arrangement arising from a given sweep of the oscillator frequency in a given sense and storing the samples thus taken, corresponding periodically sampling the input waveform to the arrangement arising from the next sweep of the oscillator frequency in the given sense and calculating the differences between the corresponding samples taken for the two sweeps, performing a Fast Fourier Transform on the differences thus calculated, periodically sampling the input waveform to the arrangement arising from a given sweep of the oscillator frequency in the opposite sense and storing the samples thus taken, correspondingly periodically sampling the input waveform to the arrangement arising from the next sweep of the oscillator frequency in the said opposite sense and calculating the differences between the corresponding samples taken for the two sweeps, and performing a Fast Fourier Transform on the differences thus calculated.

16. Apparatus for measuring the range and/or radial velocity of a moving target, substantially as described herein with reference to the drawings.

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